US009406837B2

(12) **United States Patent**
Yoo

(10) **Patent No.: US 9,406,837 B2**
(45) **Date of Patent: Aug. 2, 2016**

(54) **METHOD OF MAKING DIODE HAVING REFLECTIVE LAYER**

(71) Applicant: **LG Innotek Co. Ltd.**, Seoul (KR)

(72) Inventor: **Myung Cheol Yoo**, Pleasanton, CA (US)

(73) Assignee: **LG INNOTEK CO., LTD**, Seoul (KR)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/294,732**

(22) Filed: **Jun. 3, 2014**

(65) **Prior Publication Data**

US 2014/0273322 A1 Sep. 18, 2014

Related U.S. Application Data

(63) Continuation of application No. 13/550,097, filed on Jul. 16, 2012, now Pat. No. 8,759,129, which is a continuation of application No. 12/841,674, filed on Jul. 22, 2010, now Pat. No. 8,236,585, which is a

(Continued)

(51) **Int. Cl.**

H01L 33/00	(2010.01)
H01L 33/46	(2010.01)
H01L 33/06	(2010.01)
H01L 33/60	(2010.01)
H01L 33/32	(2010.01)
H01L 33/42	(2010.01)

(52) **U.S. Cl.**

CPC ***H01L 33/0075*** (2013.01); ***H01L 33/06*** (2013.01); ***H01L 33/46*** (2013.01); ***H01L 33/60*** (2013.01); *H01L 33/0095* (2013.01); *H01L 33/32* (2013.01); *H01L 33/42* (2013.01)

(58) **Field of Classification Search**

CPC H01L 33/0075; H01L 33/46; H01L 33/06; H01L 33/04; H01L 33/32; H01L 33/0095; H01L 33/42

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,236,296 A 12/1980 Woolhouse et al.
4,704,369 A 11/1987 Nath et al.

(Continued)

FOREIGN PATENT DOCUMENTS

DE 10056999 5/2001
EP 0622858 A2 11/1994

(Continued)

OTHER PUBLICATIONS

Fukushima, N. "High-Rate and smooth Surface Etching of Al2O3-TiC Employing Inductively Coupled Plasma (ICP)" Jpn. J. Appl. Phys. vol. 35, Part 1, No. 4B Apr. 1996 pp. 2512-2515.*

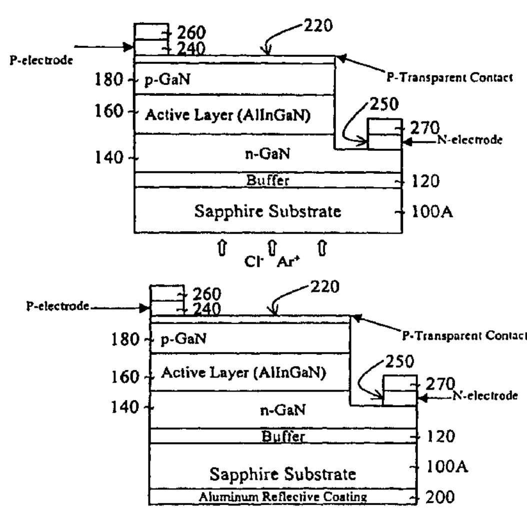
(Continued)

Primary Examiner — Matthew Landau
Assistant Examiner — Grant Withers
(74) *Attorney, Agent, or Firm* — Dentons US LLP

(57) **ABSTRACT**

A method of forming a light emitting diode includes forming a transparent substrate and a GaN buffer layer on the transparent substrate. An n-GaN layer is formed on the buffer layer. An active layer is formed on the n-GaN layer. A p-GaN layer is formed on the active layer. A p-electrode is formed on the p-GaN layer and an n-electrode is formed on the n-GaN layer. A reflective layer is formed on a second side of the transparent substrate. A scribe line is formed on the substrate for separating the diodes on the substrate. Also, a cladding layer of AlGaN is between the p-GaN layer and the active layer.

17 Claims, 11 Drawing Sheets



Related U.S. Application Data

continuation of application No. 11/713,045, filed on Mar. 2, 2007, now Pat. No. 7,785,908, which is a continuation of application No. 11/203,322, filed on Aug. 15, 2005, now Pat. No. 7,682,854, which is a continuation of application No. 09/982,980, filed on Oct. 22, 2001, now Pat. No. 6,949,395.

(56) References Cited

U.S. PATENT DOCUMENTS

5,103,269	A	4/1992	Tomomura et al.	
5,132,750	A	7/1992	Kato et al.	
5,369,289	A	11/1994	Tamaki et al.	
5,514,903	A	5/1996	Inoue et al.	
5,593,815	A	1/1997	Ahn	
5,798,536	A	8/1998	Tsutsui	
5,798,537	A	8/1998	Nitta	
5,880,486	A	3/1999	Nakamura et al.	
5,904,548	A	5/1999	Orcutt	
5,939,735	A	8/1999	Tsutsui et al.	
5,952,681	A	9/1999	Chen	
5,977,566	A	11/1999	Okazaki et al.	
6,017,774	A	1/2000	Yuasa et al.	
6,051,503	A	4/2000	Bhardwaj et al.	
6,057,565	A	5/2000	Yoshida et al.	
6,063,527	A	5/2000	Nishikawa et al.	
6,069,021	A	5/2000	Terashima et al.	
6,078,064	A	6/2000	Ming-Jiunn et al.	
6,097,040	A	8/2000	Morimoto et al.	
6,121,636	A	9/2000	Morita et al.	
6,121,638	A *	9/2000	Rennie et al.	257/103
6,130,147	A	10/2000	Major et al.	
6,146,916	A	11/2000	Nanishi et al.	
6,156,584	A	12/2000	Itoh et al.	
6,185,238	B1	2/2001	Onomura et al.	
6,194,742	B1	2/2001	Kern et al.	
6,211,089	B1	4/2001	Kim et al.	
6,242,276	B1	6/2001	Baek et al.	
6,242,761	B1	6/2001	Fujimoto et al.	
6,249,534	B1	6/2001	Itoh et al.	
6,252,255	B1	6/2001	Ueta et al.	
6,274,399	B1	8/2001	Kern et al.	
6,281,524	B1	8/2001	Yamamoto et al.	
6,291,257	B1	9/2001	Kadota	
6,360,687	B1	3/2002	Yanagisawa et al.	
6,365,429	B1	4/2002	Kneissl et al.	
6,375,790	B1	4/2002	Fenner	
6,379,985	B1	4/2002	Cervantes et al.	
6,388,275	B1	5/2002	Kano	
6,404,792	B1	6/2002	Yamamoto et al.	
6,448,102	B1	9/2002	Kneissi	
6,456,638	B1	9/2002	Fukunaga	
6,468,902	B2	10/2002	Kawai	
6,486,042	B2	11/2002	Gehrke et al.	
6,488,767	B1	12/2002	Xu et al.	
6,489,250	B1	12/2002	Hwang et al.	
6,492,661	B1	12/2002	Chien et al.	
6,504,180	B1	1/2003	Heremans et al.	
6,518,602	B1	2/2003	Yuasa et al.	
6,526,083	B1	2/2003	Kneissl et al.	
6,562,648	B1	5/2003	Wong et al.	
6,564,445	B1	5/2003	Hashimoto et al.	
6,570,186	B1	5/2003	Uemura et al.	
6,576,933	B2	6/2003	Nitta et al.	
6,579,802	B1 *	6/2003	Pierson	H01L 21/30621 257/E21.222
6,580,099	B2	6/2003	Nakamura et al.	
6,586,149	B2	7/2003	Kawamura et al.	
6,586,777	B1	7/2003	Yuasa et al.	
6,597,716	B1	7/2003	Takatani	
6,627,921	B2	9/2003	Wong et al.	
6,638,846	B2	10/2003	Iwata et al.	
6,693,352	B1	2/2004	Huang et al.	
6,720,583	B2	4/2004	Nunoue et al.	
6,744,196	B1	6/2004	Jeon	
6,765,232	B2	7/2004	Kaminishi et al.	
6,787,435	B2	9/2004	Gibb et al.	
6,812,071	B2	11/2004	Hayashi et al.	
6,815,725	B2	11/2004	Sugawara et al.	
6,819,701	B2	11/2004	Henrichs	
6,841,802	B2	1/2005	Yoo	
6,869,820	B2	3/2005	Chen	
6,939,735	B2	9/2005	Smith et al.	
6,949,395	B2	9/2005	Yoo	
7,067,849	B2	6/2006	Yoo	
7,087,933	B2	8/2006	Takeda	
7,148,520	B2	12/2006	Yoo	
7,205,576	B2	4/2007	Song	
7,250,638	B2	7/2007	Lee et al.	
7,265,392	B2	9/2007	Hahn	
7,291,865	B2	11/2007	Kojima et al.	
7,294,521	B2	11/2007	Yoo	
7,319,247	B2	1/2008	Bader	
7,371,597	B2	5/2008	Yoo	
7,384,808	B2	6/2008	Liu	
7,462,881	B2	12/2008	Lee et al.	
7,498,611	B2	3/2009	Eitoh et al.	
7,518,153	B2	4/2009	Usuda et al.	
7,563,629	B2	7/2009	Lee et al.	
7,566,639	B2	7/2009	Kohda	
7,569,865	B2	8/2009	Lee et al.	
7,576,368	B2	8/2009	Lee et al.	
7,582,912	B2	9/2009	Yoo	
7,588,952	B2	9/2009	Lee et al.	
7,649,210	B2	1/2010	Yoo	
7,682,854	B2	3/2010	Yoo	
7,691,650	B2	4/2010	Yoo	
7,741,653	B2	6/2010	Kamei	
7,772,020	B2	8/2010	Yoo	
7,816,705	B2	10/2010	Lee et al.	
7,821,021	B2	10/2010	Yoo	
7,863,638	B2	1/2011	Yoo	
7,875,474	B2	1/2011	Muraki et al.	
7,928,465	B2	4/2011	Lee	
7,939,849	B2	5/2011	Yoo	
8,022,386	B2	9/2011	Yoo	
8,106,417	B2	1/2012	Yoo	
8,236,585	B2	8/2012	Yoo	
8,288,787	B2	10/2012	Yoo	
8,294,172	B2	10/2012	Yoo	
8,309,982	B2	11/2012	Hanawa	
8,368,115	B2	2/2013	Yoo	
8,384,091	B2	2/2013	Yoo	
8,384,120	B2	2/2013	Lee	
8,445,921	B2	5/2013	Yoo	
8,502,256	B2 *	8/2013	Lee	257/98
2001/0000335	A1	4/2001	Yamada	
2001/0010941	A1	8/2001	Morita	
2001/0023946	A1	9/2001	Ueta et al.	
2001/0028062	A1	10/2001	Uemura et al.	
2001/0030316	A1	10/2001	Kuramoto	
2001/0030329	A1	10/2001	Ueta et al.	
2001/0041410	A1	11/2001	Franz	
2002/0037602	A1	3/2002	Okada et al.	
2002/0117672	A1	8/2002	Chu et al.	
2002/0117681	A1	8/2002	Weeks et al.	
2002/0117695	A1	8/2002	Borges et al.	
2002/0123164	A1	9/2002	Slater, Jr. et al.	
2002/0137249	A1 *	9/2002	Ishida et al.	438/47
2002/0146854	A1	10/2002	Koide et al.	
2002/0173062	A1 *	11/2002	Chen et al.	438/30
2002/0177251	A1	11/2002	Ye et al.	
2003/0015713	A1	1/2003	Yoo	
2003/0032297	A1	2/2003	Lindstrom et al.	
2003/0073321	A1	4/2003	Boiteux et al.	
2003/0077847	A1	4/2003	Yoo	
2003/0080344	A1	5/2003	Yoo	
2003/0122141	A1	7/2003	Wong et al.	
2003/0151058	A1	8/2003	Uemura et al.	
2003/0189212	A1	10/2003	Yoo	
2003/0189215	A1	10/2003	Lee et al.	
2003/0213969	A1	11/2003	Wang et al.	
2004/0000672	A1	1/2004	Fan et al.	
2004/0169181	A1	9/2004	Yoo	

(56) **References Cited**

U.S. PATENT DOCUMENTS

2004/0169189	A1	9/2004	Jeon	
2005/0093004	A1	5/2005	Yoo	
2005/0098792	A1	5/2005	Lee et al.	
2006/0006400	A1	1/2006	Yoo	
2006/0027818	A1	2/2006	Yoo	
2006/0071226	A1	4/2006	Kojima et al.	
2006/0071230	A1	4/2006	Lee et al.	
2006/0091420	A1	5/2006	Yoo	
2006/0094207	A1	5/2006	Yoo	
2006/0097277	A1	5/2006	Yoo	
2006/0099730	A1	5/2006	Lee et al.	
2006/0244001	A1	11/2006	Lee et al.	
2007/0018173	A1	1/2007	Yoo	
2007/0057273	A1	3/2007	Yoo	
2007/0172973	A1	7/2007	Yoo	
2007/0269913	A1*	11/2007	Kim et al.	438/22
2007/0290224	A1	12/2007	Ogawa	
2007/0295986	A1	12/2007	Lee et al.	
2008/0001166	A1	1/2008	Lee et al.	
2008/0064132	A1	3/2008	Yoo	
2008/0128733	A1	6/2008	Yoo	
2008/0182384	A1	7/2008	Hata	
2009/0008654	A1*	1/2009	Nagai	257/88
2009/0072264	A1	3/2009	Yoo	
2009/0121241	A1	5/2009	Keller et al.	
2009/0267100	A1*	10/2009	Miyake et al.	257/98
2009/0278140	A1*	11/2009	Huang et al.	257/88
2009/0278161	A1	11/2009	Lee et al.	
2010/0012956	A1	1/2010	Yoo	
2010/0109020	A1	5/2010	Yoo	
2010/0117096	A1	5/2010	Yoo	
2010/0127274	A1	5/2010	Yoo	
2010/0129943	A1	5/2010	Yoo	
2010/0171125	A1	7/2010	Yoo	
2010/0207145	A1	8/2010	Yoo	
2010/0314607	A1	12/2010	Yoo	
2011/0095331	A1	4/2011	Hanawa	
2011/0193128	A1	8/2011	Lee	
2011/0220948	A1	9/2011	Yoo	
2011/0309400	A1*	12/2011	Fukushima et al.	257/98
2012/0098023	A1*	4/2012	Weng et al.	257/99
2013/0134465	A1	5/2013	Yoo	
2013/0146928	A1*	6/2013	Inoue et al.	257/98
2013/0240945	A1*	9/2013	Aoki et al.	257/99
2013/0260490	A1*	10/2013	Shatalov et al.	438/27
2013/0328057	A1*	12/2013	Yu et al.	257/76
2014/0124730	A1*	5/2014	Choi et al.	257/13

FOREIGN PATENT DOCUMENTS

EP	0852816	A2	7/1998
EP	0892443	A2	1/1999
EP	1017113	A1	7/2000
JP	05129658	A	5/1993
JP	7-273368		10/1995
JP	0832116	A	2/1996
JP	9-307189		11/1997
JP	10-044139		2/1998
JP	10270754	A	10/1998
JP	11-126925		5/1999
JP	2001-217456	A	8/2001
JP	2001-284642		10/2001
KR	10-1998-0086740		12/1998

OTHER PUBLICATIONS

Hsiao, R. "Fabrication of magnetic recording heads and dry etching of head materials" IBM Journal of Research and Development vol. 43, No. 1/2, Mar. 1999 pp. 89-102.*

Michael Kneissl, et al., "Continuous-Wave Operation of InGaN Multiple-Quantum-Well Laser Diodes on Copper Substrates Obtained by Laser Liftoff", IEEE Journal on Selected Topics in Quantum Electronics, vol. 7, No. 2, Mar./Apr. 2001; pp. 188-191.

William S. Wong, et al., "Continuous-Wave InGaN Multiple-Quantum-Well Laser Diodes on Copper Substrates", Applied Physics Letters vol. 78, No. 9, Feb. 26, 2001; pp. 1198-1200.

William S. Wong, et al., "The integration of $In_xGa_{1-x}N$ Multiple-Quantum-Well Laser Diodes with Copper Substrates by Laser Lift-Off", Jpn. J. Appl. Phys. vol. 39 (2000) pp. L 1203-L 1205, Part 2, No. 12A, Dec. 1, 2000; pp. L1203-L1205.

Y.J. Sung, et al., "High Rate Etching of Sapphire Wafer Using $C1_2$/BCI_3/Ar Inductively Coupled Plasmas," Materials Science & Engineering B, XP-001150272, pp. 50-52, May 22, 2001.

Wolf, S., "Silicon Processing for the VLSI Era", vol. 12nd ed. (200), pp. 698 and 708.

Kwok, C.K., et al. "Designing an External Efficient of Over 30% for Light Emitting Diode", IEEE, 1998, pp. 187-188.

Continuous/Wave Operation of InGaN Multiple/Quantum/Well Laser Diodes on Copper Substrates Obtained by Laser Liftoff, IEEE Journal on Selected Topics in Quantum Electronics, vol. 7, No. 2, March/04il 2001.

Continuous/Wave InGaN Multiple/Quantum/Well Laser Diodes on Copper Substrates, Applied Physics Letters vol. 78, No. 9, 26 02ruary 2001.

The integration of $In_xGa_{1/x}N$ Multiple/Quantum/Well Laser Diodes with Copper Substrates by Laser Lift/Off, Jpn. J. Appl. Phys. vol. 39 (2000) pp. L 1203/L 1205, Part 2, No. 12A, 1 12ember 2000.

Sung, et al. "High rate etching of sapphire wafer using CL2/BCL3/AR inductively coupled plasmas", Materials Science and engineering 882 (2001) p. 50-52.

Ghosh, D.S. "Widely transparent electrodes based on ultrathin metals" Opt. Lett. vol. 34, Iss. 3 Feb. 21, 2009 pp. 325-327.

Nakamura, Shuji "Superbright Green InGaN Single-Quantum-Well-Structure Light-Emitting Diodes" Jpn. J. Appl. Phys. vol. 34, Part 2, No. 1 OB 1 Oct. 15, 1995 pp. L 1332-L 1335.

Kim, D. W. "A study of transparent indium tin oxide (ITO) contact to p-GaN" Thin Solid Films 398-399 Nov. 2001 pp. 87-92.

Song, Jun. "Ohmic-Contact Technology for GaN-Based Light-Emitting Diodes: Role of P-type contact" IEEE Trans. on Elect. Dev. vol. 57, No. 1 Jan. 2010 pp. 42-59.

Qiao, D. "A study of the Au/Ni ohmic contact on p-GaN" jour. of Appl. Physics 88, 4196 Oct. 1, 2000 pp. 4196-2000.

Jang, Ja-Soon "Ohmic contacts top-type GaN using a Ni/Pt/Au metallization scheme" J. Vac. Sci. Techno I. B 16, 3105 Dec. 1998 pp. 3105-3107.

Chu, Chen-Fu "Low-resistance ohmic contacts on p-type GaN using Ni/Pd/Au metallization" Appl. Phys. Lett. 77, 3423 Nov. 20, 2000 pp. 3423-3425.

Kim, Taek "Low Resistance Contacts to P-type GaN" Mat. Res. Soc. Symp. Proc. vol. 468 copyright 1997 pp. 427-430.

Kim, Jong K. "Low resistance Pd/Au ohmic contacts top-type GaN using surface treatment" App. Phys. Lett. 73, 2953 Nov. 16, 1998 pp. 2953-2955.

Zhou, L. "Low Resistance Ti/Pt/Au ohmic contacts top-type GaN" Appl. Phys. Lett. 76, 3451 Jun. 5, 2000 pp. 3451-3453.

Motayed, Abhishek "Two-step surface treatment technique: Realization of nonalloyed low-resistance Ti/Ai/Ti/Au ohmic contact to n-GaN" J. Vac. Sci. Tech. B 22(2) Apr. 2004 pp. 663-667.

Fung, A. K. "A Study of the Electrical Characteristics of Various Metals on p-Type GaN for Ohmic contacts" Joun. of Elec. Mat. vol. 28, No. 5 May 1, 1999 pp. 572-579.

Cho, H. K. "Characterization of Pd/Ni/Au ohmic contacts on p-GaN" Solid-State Elec. 49 copyright 2005 pp. 774-778.

Fan, Zhifang "Very low resistance multilayer Ohmic contact to nGaN" Appl. Phys. Lett 68, 1672 Mar. 18, 1996.

* cited by examiner

Fig. 1

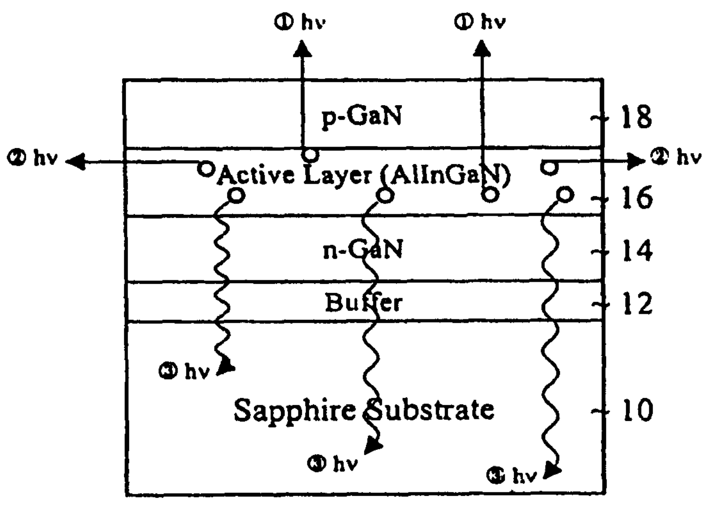

① hv
① hv
p-GaN
18
② hv
Active Layer (AlInGaN)
② hv
16
n-GaN
14
Buffer
12
③ hv
Sapphire Substrate
10
③ hv
③ hv

Fig. 2A

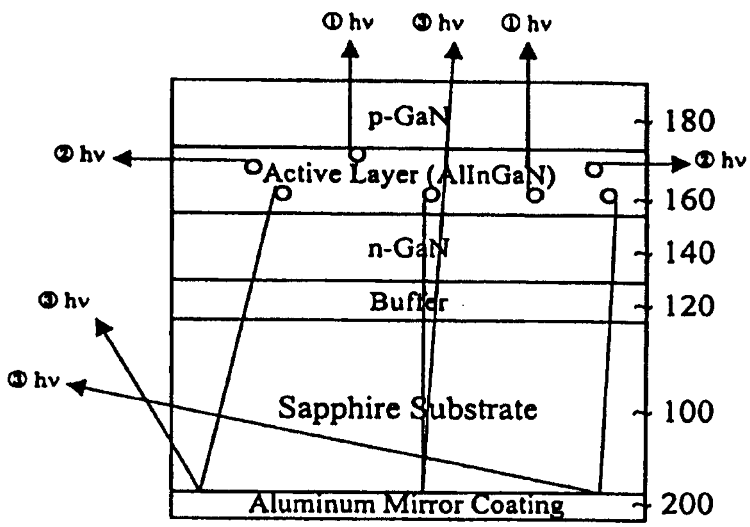

① hν
③ hν
① hν
② hν
② hν
③ hν
③ hν
p-GaN
Active Layer (AlInGaN)
n-GaN
Buffer
Sapphire Substrate
Aluminum Mirror Coating
180
160
140
120
100
200

Fig. 2B

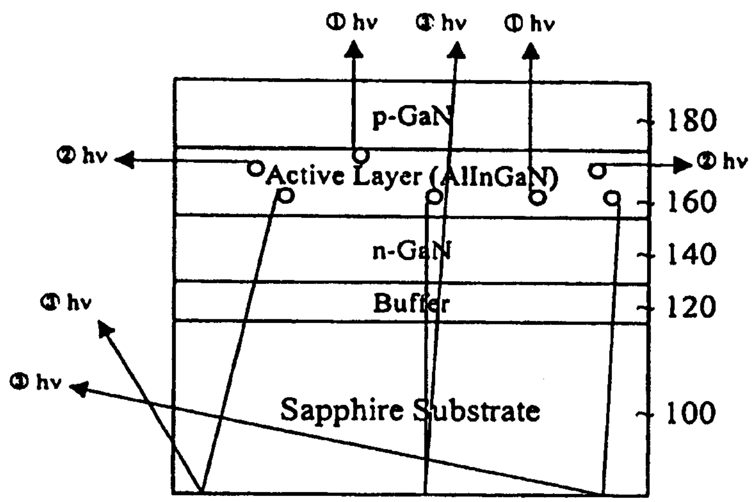

① hv
③ hv
① hv
② hv
② hv
p-GaN
180
Active Layer (AlInGaN)
160
n-GaN
140
Buffer
120
③ hv
① hv
Sapphire Substrate
100

Fig. 3A

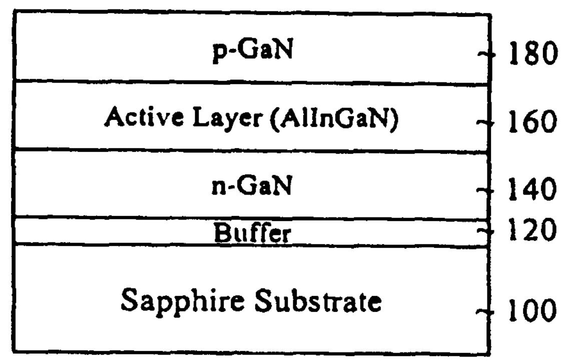

p-GaN
180
Active Layer (AlInGaN)
160
n-GaN
140
Buffer
120
Sapphire Substrate
100

Fig. 3B

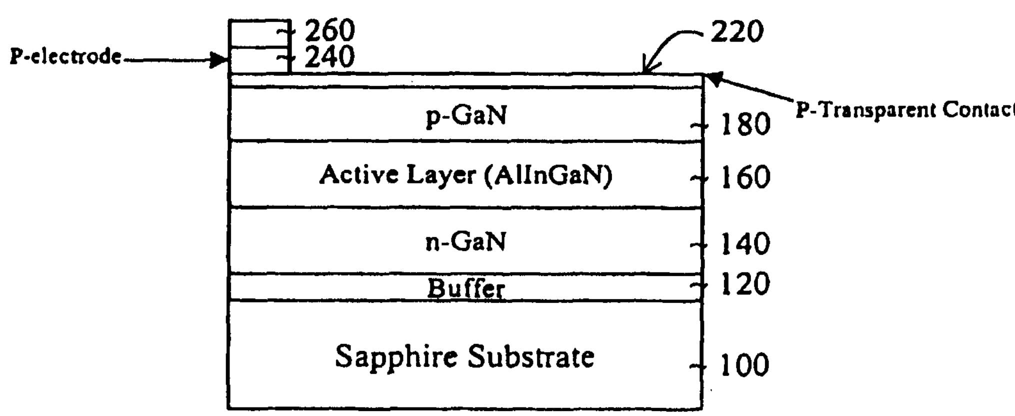
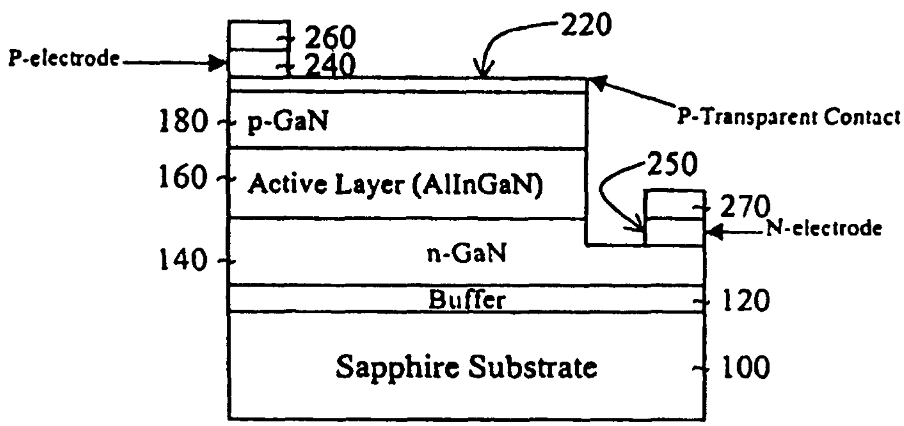
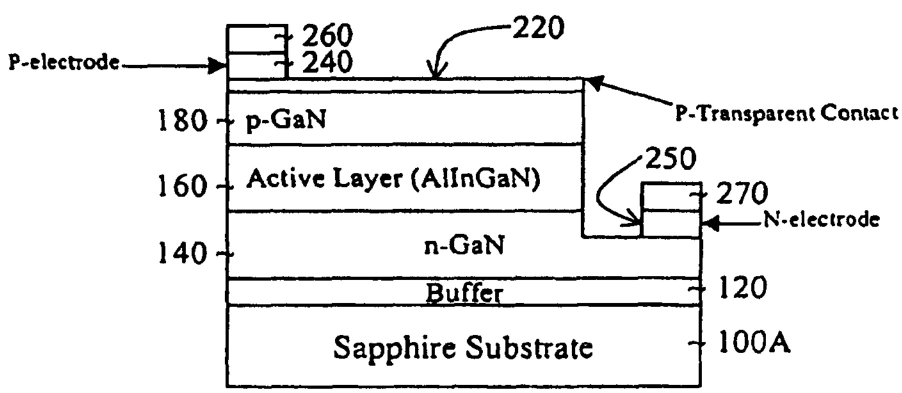

260
240
P-electrode
220
P-Transparent Contact
p-GaN
180
Active Layer (AlInGaN)
160
n-GaN
140
Buffer
120
Sapphire Substrate
100

Fig. 3C



260
240
220
P-electrode
P-Transparent Contact
180
p-GaN
160
Active Layer (AlInGaN)
250
270
N-electrode
140
n-GaN
Buffer
120
Sapphire Substrate
100

Fig. 3D



260
240
220
P-electrode
P-Transparent Contact
180
p-GaN
160
Active Layer (AlInGaN)
250
270
N-electrode
140
n-GaN
Buffer
120
Sapphire Substrate
100A

Fig. 3E

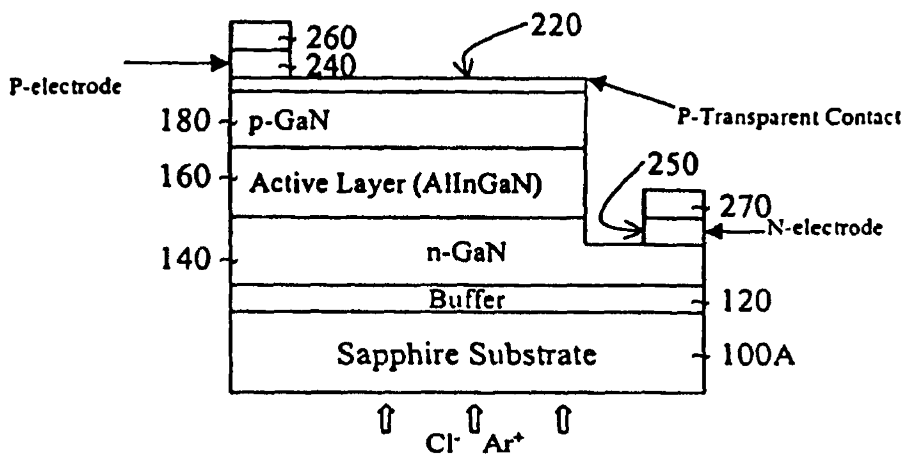

260
240
220
P-electrode
P-Transparent Contact
180
p-GaN
160
Active Layer (AlInGaN)
250
270
N-electrode
140
n-GaN
Buffer
120
Sapphire Substrate
100A
Cl-
Ar+

Fig. 3F

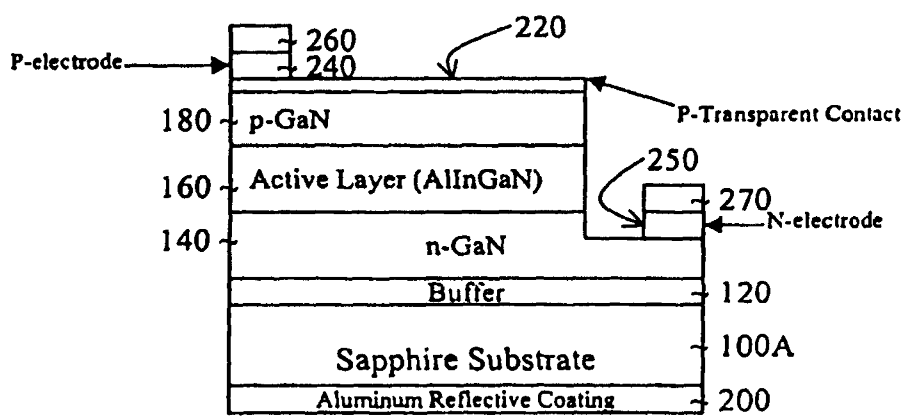

260
240
220
P-electrode
P-Transparent Contact
180
p-GaN
160
Active Layer (AlInGaN)
250
270
N-electrode
140
n-GaN
Buffer
120
Sapphire Substrate
100A
Aluminum Reflective Coating
200

Fig. 4A

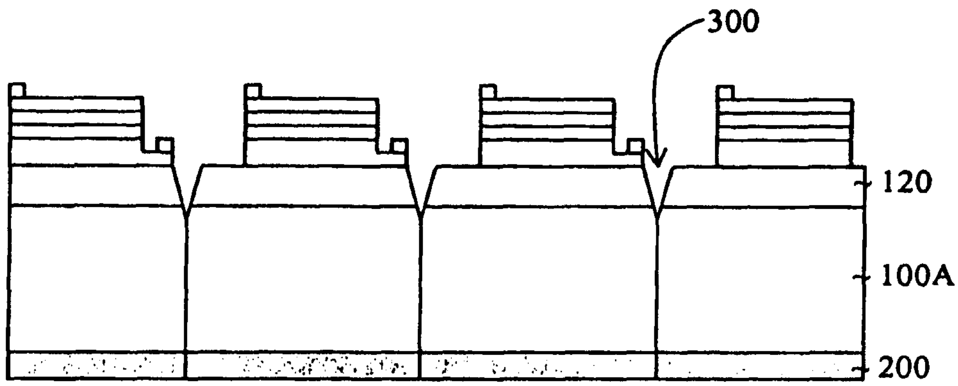


Fig. 4B

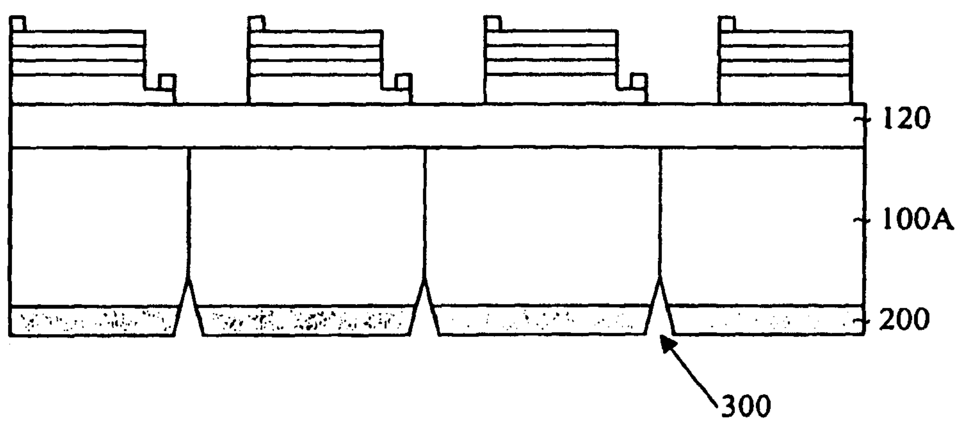


Fig. 5

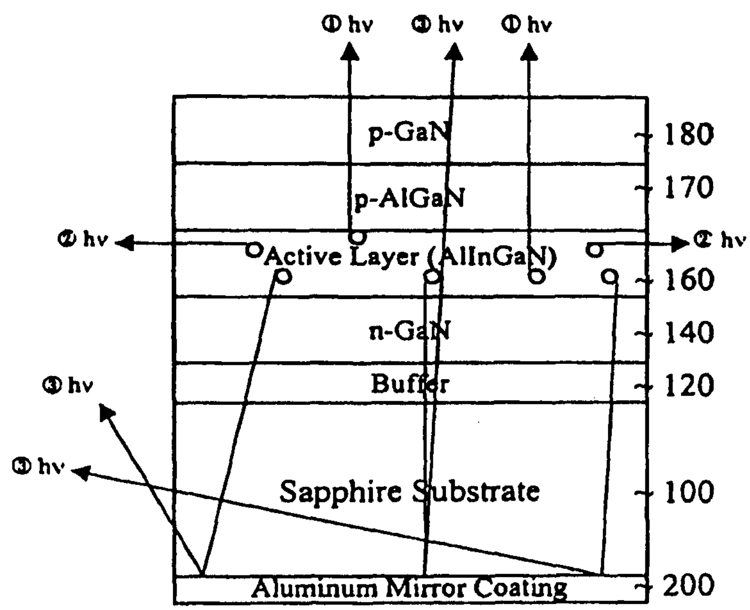

① hν
① hν
① hν
p-GaN
180
p-AlGaN
170
② hν
Active Layer (AlInGaN)
② hν
160
n-GaN
140
③ hν
Buffer
120
③ hν
Sapphire Substrate
100
Aluminum Mirror Coating
200

FIG. 6

Light Output vs. Current Injection

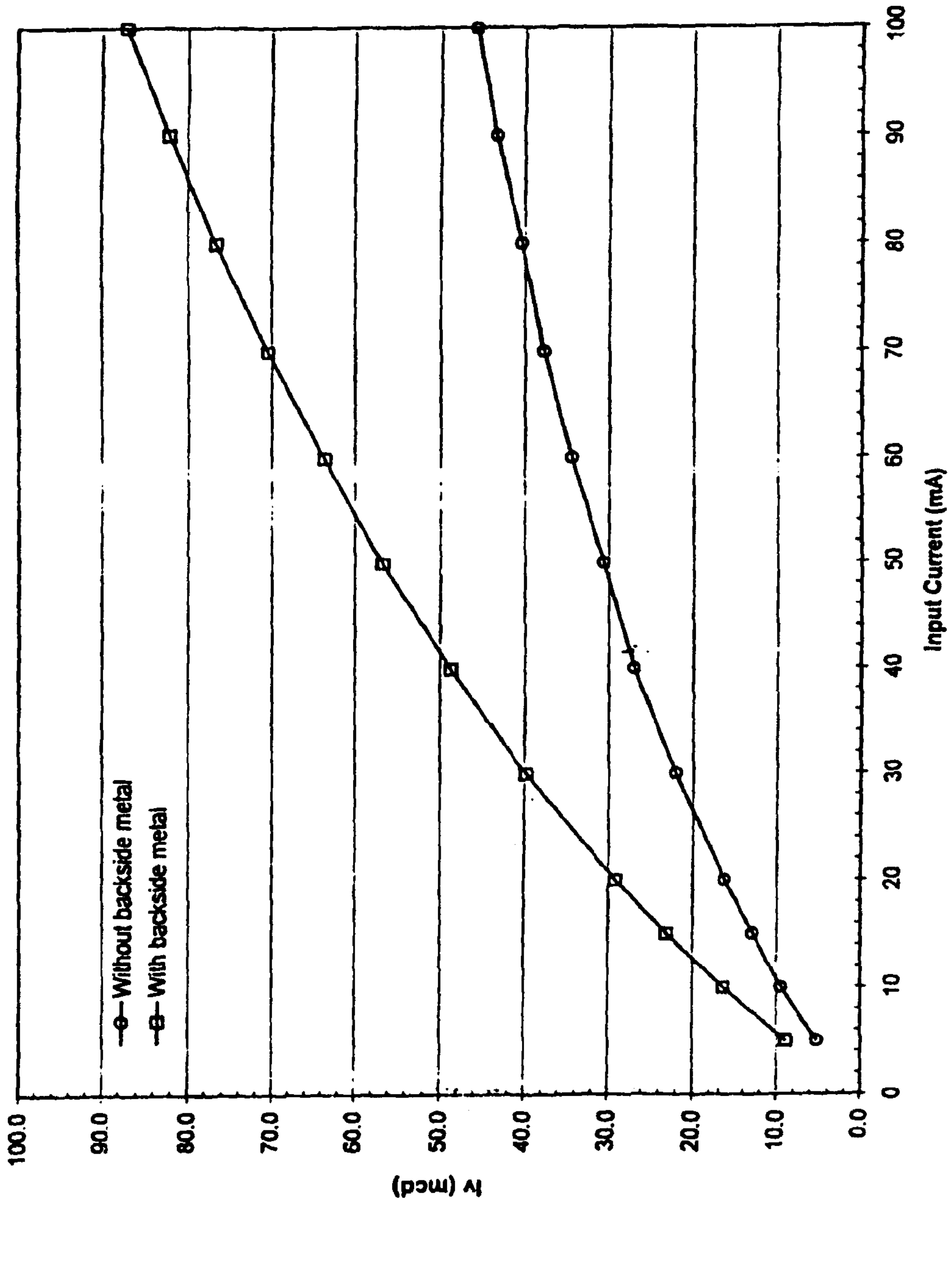
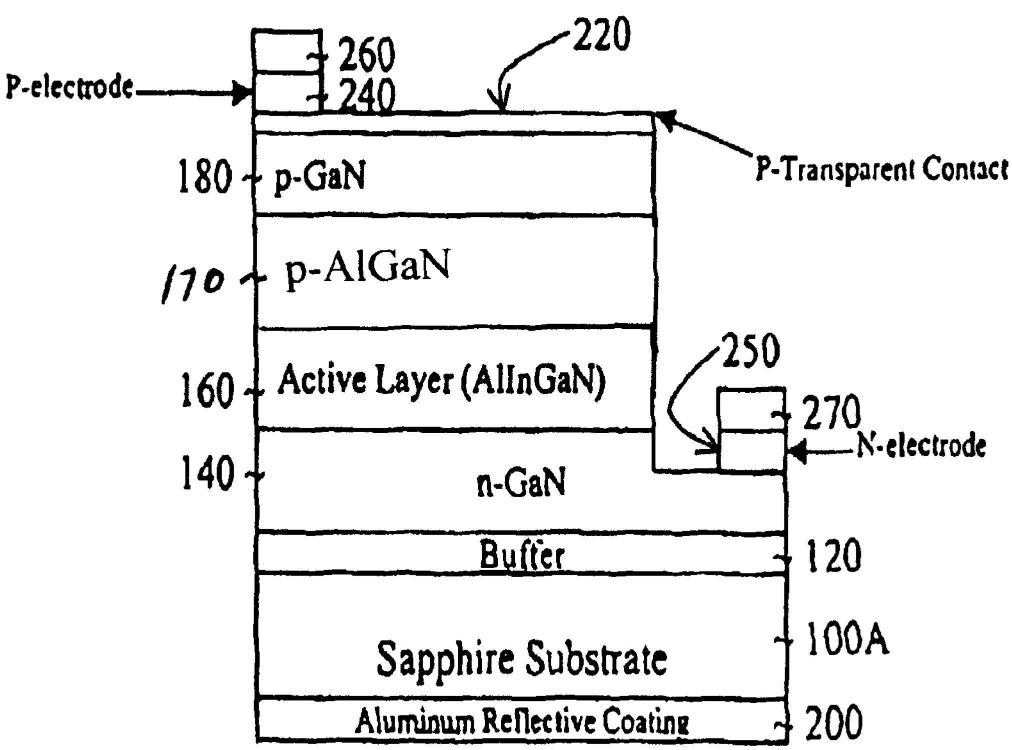


Fig. 7


220
260
P-electrode
240
180
p-GaN
P-Transparent Contact
170
p-AlGaN
250
160
Active Layer (AlInGaN)
270
N-electrode
140
n-GaN
Buffer
120
Sapphire Substrate
100A
Aluminum Reflective Coating
200

METHOD OF MAKING DIODE HAVING REFLECTIVE LAYER

This application is a continuation of application Ser. No. 13/550,097, filed Jul. 16, 2012, which is a continuation of application Ser. No. 12/841,674 filed Jul. 22, 2010, (now U.S. Pat. No. 8,236,585), which is a continuation of application Ser. No. 11/713,045, filed Mar. 2, 2007 (now U.S. Pat. No. 7,785,908), which is a continuation of application Ser. No. 11/203,322 filed Aug. 15, 2005 (now U.S. Pat. No. 7,682, 854), which is a continuation of application Ser. No. 09/982, 980 filed Oct. 22, 2001 (now U.S. Pat. No. 6,949,395), all of which are hereby incorporated by reference for all purposes as if fully set forth herein.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to diodes, and more particularly, to light emitting diodes (LEDs). Although the present invention is discussed with reference to light emitting diodes, the present invention can be used in a wide range of applications including, for example, other types of diodes such as laser diodes.

2. Discussion of the Related Art

Gallium-Nitride (GaN) based opto-electronic device technology has rapidly evolved from the realm of device research and development to commercial reality. Since they have been introduced in the market in 1994, GaN-based opto-electronic devices have been considered one of the most promising semiconductor devices. The efficiency of GaN light emitting diodes (LEDs), for example, has surpassed that of incandescent lighting, and is now comparable with that of fluorescent lighting.

The market growth for GaN based devices has been far exceeding than the industrial market prediction every year. In some applications, such as traffic lights and interior lighting in automobiles, the low maintenance cost and reduced power consumption of GaN LED's already outweigh the relatively high manufacturing costs. In other applications such as general room lighting, manufacturing costs are still much too high, and a simple economy of scale reveals that such devices are not yet the solution. Although considerably more demanding of materials quality and device design, room temperature, continuous wave blue lasers with reasonable lifetimes have been demonstrated. Their continued development combined with the potentially high-volume market should bring costs to acceptable levels, provided that they can be manufactured with high yield. GaN-based high-power electronic devices should also find application in mobile communications, another high-volume market. In order to expand the current AlInGaN-based LED market, it is crucial to develop low cost processing techniques without sacrificing device performances. Moreover, high power optical devices are strongly needed to replace the light bulb lamps. Accordingly, two important technical issues need to be solved at the same time, i.e., economical device production and high output power device fabrication.

Outdoor signboard display has been one of the primary markets since the introduction of blue LEDs. In such application, the light output is considered one of the most important device parameters in AlInGaN-based LEDs. As a result, the unit device price is approximately proportional to the light output intensity. Moreover, recently, the white LED application requires higher light output than currently available to replace the incandescent light bulbs for illumination. Therefore, developing a technology to increase light output is one of the most important tasks in the AlInGaN-based opto-electronic devices.

FIG. **1** shows a conventional light emitting diode structure. The conventional LED includes a substrate **10**, such as sapphire. A buffer layer **12** made of, for example, gallium nitride (GaN) is formed on the substrate **10**. An n-type GaN layer **14** is formed on the buffer layer **12**. An active layer such as a multiple quantum well (MQW) layer **16** of AlInGaN, for example, is formed on the n-type GaN layer **14**. A p-type GaN layer **18** is formed on the MQW layer **16**.

The MQW layer emits photons "hv" in all directions to illuminate the LED. FIG. **1** shows directions **1**, **2** and **3** for convenience. Photons traveling in directions **1** and **2** contribute to the intensity of the LED. However, photons traveling in direction **3** become absorbed by the substrate and the package which house the LED. This photon absorption decreases the light extraction efficiency resulting in reduced brightness of the LED.

There are two main methods to increase light output of the AlInGaN-based LEDs. The first method is to improve external quantum efficiency of the LED device by epitaxial growth and device structure design. This technique requires high quality epitaxial growth techniques that include MOCVD (Metal Organic Chemical Vapor Deposition), MBE (Molecular Beam Epitaxy), and HVPE (Hydride Vapor Phase Epitaxy) and sophisticated device design. In particular, MOCVD has been the most common growth tool to grow commercial grade AlInGaN-based LEDs. It is generally known that the epitaxial film quality is strongly dependent on the types of MOCVD growth method. Hence, in the manufacturing point of view, it is more difficult to improve optical light output of the LED devices by such growth technique.

Another method to enhance the optical light output is increasing the light extraction efficiency by optimizing the LED chip design. Compared to the method of increasing external quantum efficiency by epitaxial growth and device structure design, this method is much simpler and easier to increase the light intensity of the LED device. There have been many attempts to design the most efficient device design. However, thus far, these attempts have not led to the level of efficiency and brightness desired from the diode. Moreover, existing designs require high manufacturing cost. Accordingly, a diode is needed that has high brightness capability, an efficient design and low manufacturing cost.

SUMMARY OF THE INVENTION

Accordingly, the present invention is directed to a diode that substantially obviates one or more of the problems due to limitations and disadvantages of the related art.

An advantage of the present invention is providing a diode having high brightness.

Additional features and advantages of the invention will be set forth in the description which follows, and in part will be apparent from the description, or may be learned by practice of the invention. The objectives and other advantages of the invention will be realized and attained by the structure particularly pointed out in the written description and claims hereof as well as the appended drawings.

To achieve these and other advantages and in accordance with the purpose of the present invention, as embodied and broadly described, a light emitting diode comprises a transparent substrate; a buffer layer on a first surface of the transparent substrate; an n-GaN layer on the buffer layer; an active layer on the n-GaN layer; a p-GaN layer on the active layer; a p-electrode on the p-GaN layer; an n-electrode on the n-GaN layer; and a reflective layer on a second side of the transparent substrate.

In another aspect, a method of making a light emitting diode having a transparent substrate and a buffer layer on a first surface of the transparent substrate comprises forming an n-GaN layer on the buffer layer; forming an active layer on the n-GaN layer; forming a p-GaN layer on the active layer; forming a p-electrode on the p-GaN layer; forming an n-electrode on the n-GaN layer; forming a reflective layer on a second side of the transparent substrate; and forming scribe lines on the transparent substrate.

In another aspect, a method of making a light emitting diode having a transparent substrate and a buffer layer on a first surface of the transparent substrate comprises forming an n-GaN layer on the buffer layer; forming an active layer on the n-GaN layer; forming a p-GaN layer on the active layer; forming a p-electrode on the p-GaN layer; forming an n-electrode on the n-GaN layer; forming a reflective layer on a second side of the transparent substrate; and forming scribe lines on the transparent substrate.

In another aspect, a method of making a light emitting diode having a substrate comprises forming an n-type layer and a p-type layer on the substrate; forming an active layer between the n-type layer and the p-type layer; forming a first electrode contacting the p-type layer; forming a second electrode contacting the n-type layer; forming a reflective layer on the substrate; and forming scribe lines on the substrate.

In another aspect, a diode comprises a transparent substrate; an active layer on the transparent substrate, the active layer generating photons; and a reflective layer on the transparent substrate to reflect the photons from the active layer.

In another aspect, a method of making a diode comprises forming an active layer over a transparent substrate, the active layer generating photons; forming a reflective layer on the transparent substrate to reflect the photons from the active layer; and forming scribe lines on the substrate.

In another aspect, a method of making a light emitting diode having a transparent substrate comprises forming an n-GaN layer having a first doping concentration on a first side of the transparent substrate; forming an InGaN active layer on the n-GaN layer, the active layer having an In concentration in a first range; forming a p-GaN layer having a second doping concentration on the InGaN active layer; forming a p-type contact layer on the p-GaN layer; forming an n-type contact layer on the n-GaN layer by etching the p-type contact layer, p-GaN layer and the InGaN active layer; reducing a thickness of the transparent substrate by backside lapping at a second surface of the transparent substrate; reducing a surface roughness of the transparent substrate; forming a reflective layer on a reduced surface of the transparent substrate; and forming scribe lines on the transparent substrate.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWING

The accompanying drawings, which are included to provide a further understanding of the invention and are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and together with the description serve to explain the principles of the invention.

In the drawings:

FIG. **1** generally shows a conventional light emitting diode;

FIGS. **2**A and **2**B show two different embodiments of a light emitting diode of the present invention;

FIG. **3**A-**3**F shows the manufacturing steps for forming the light emitting diode of the present invention;

FIGS. **4**A and **4**B each show a wafer having the light emitting diodes with scribe lines;

FIG. **5** shows another embodiment of the diode of the present invention;

FIG. **6** is a graph showing a relationship between light output and current injection for an LED having a reflective layer of the present invention and an LED without a reflective layer; and

FIG. **7** shows another embodiment of the diode of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Reference will now be made in detail to the present invention, examples of which are illustrated in the accompanying drawings.

In order to fabricate GaN-based light emitting diodes (LEDs), sapphire substrate has been generally used since sapphire is very stable and relatively cheaper. The epitaxial layer quality of the AlInGaN grown on sapphire substrate is superior to the other substrate material due to their thermal stability and the same crystal structure of the GaN. However, there are some disadvantages in using sapphire as a substrate material for AlInGAN-based LED device fabrication. Because the sapphire is insulator, forming an n-type bottom contact is not possible. In addition, it is very difficult to perform the post fabrication processes that include the grinding, the polishing, and the scribing since sapphire is almost as hard as diamond. However, transparent sapphire substrate is beneficial for the light extraction compare to the other non-transparent compound semiconductor material such as GaAs and InP.

Nevertheless, it has not been possible to take advantage of this important benefit. When sapphire is used for the substrate, p and n electrodes should be placed on the same top electrode position. As a result, as shown in FIG. **1**, the downward photons emitted in the active region can suffer absorption by thick substrate and the lead frame. Hence, only photons directing top portion and edge emitting can contribute to the optical output power. On the other hand, if a reflecting surface is provided in the bottom sapphire substrate, in addition to the top emitting and edge emitting photons, the photons emitted to the downward direction can be reflected to the side-wall of the sapphire substrate or can be reflected back to the top surface. In addition to the backside reflective coating, the light output can be increased by making a mirror-like or highly smooth interface between the reflective metal layer and the transparent substrate. Depending on the reflective index of the substrate material and the surface conditions, including surface roughness, there is a certain angle called an escaping angle in which the photons from the active layer reflect off of the interface back to the substrate crystal. Therefore, at a fixed reflective index of the sapphire substrate, for example, the amount of reflected photons can be controlled by reducing the surface roughness of the substrate. In the present invention, a new surface polishing technique is employed in addition to the conventional mechanical polishing techniques. An atomically flat sapphire surface was obtained using an inductively coupled plasma reactive ion beam etching (ICPRIE). By using ICPRIE, the sapphire surface having a surface roughness as small as 1 nm was obtained. Moreover, the transmitted or escaped photons can be reflected back off of the smooth surface to the substrate crystal. This results in a considerable enhancement of the total optical light output of the LED device.

FIG. **2**A illustrates an LED structure of the present invention. The light emitting diode structure includes substrate **100**, which is a transparent substrate, such as sapphire. The sapphire has undergone backside lapping and polishing on its back surface to maximize the light output. Prior to the reflective metal coating, ICPRIE polishing was performed on a mechanically polished sapphire substrate to further reduce the surface roughness. In one sample, the ICPRIE polishing process conditions were as follows:

1600 watt RF power;
−350V substrate bias voltage;
gas mixture of 18% Cl_2/72% BCl_3/20% As;
20 degree Celsius substrate temperature;
40 minutes etching time; and
resulting etch rate was 350 nm/min, respectively.

Referring to FIG. **2**A, a reflective layer **200** is on the sapphire substrate **100** and can be made of an aluminum mirror, for example, to reflect the photons heading toward the bottom. The reflected photons contribute to dramatically increasing the brightness of the LED. As will be discussed throughout the description, the material for the reflective layer is not limited to aluminum but may be any suitable material that will reflect the photons to increase the brightness of the LED. Moreover, the substrate of the LED may also be made of suitable materials other than sapphire.

FIG. **2**B illustrates another LED structure of the present invention. In FIG. **2**B, the reflective layer is omitted. Although the reflective layer is omitted, the sapphire substrate **100** is polished using ICPRIE, for example, to maximize the smoothness of the surface of the surface. Such smooth surface allows the photons from the active layer directed toward the sapphire substrate to reflect off from the smooth surface of the sapphire surface to enhance the light output.

FIGS. **3**A-**3**F illustrate the steps of making a light emitting diode, as an example application of the present invention.

Referring to FIG. **3**A, a buffer layer **120** is formed on a substrate **100**. The substrate **100** is preferably made from a transparent material including for example, sapphire. In addition to sapphire, the substrate can be made of zinc oxide (ZnO), gallium nitride (GaN), silicon carbide (SiC) and aluminum nitride (AlN). The buffer layer **120** is made of, for example, GaN (Gallium Nitride) and, in this instance, the GaN was grown on the surface of the sapphire substrate **100**. An n-type epitaxial layer such as n-GaN **140** is formed on the buffer layer **120**. In this instance, the n-GaN layer **140** was doped with silicon (Si) with a doping concentration of about 10^{17} cm^{-3} or greater. An active layer **160** such as an AlInGaN multiple quantum well layer is formed on the n-GaN layer **140**. The active layer **160** may also be formed of a single quantum well layer or a double hetero structure. In this instance, the amount of indium (In) determines whether the diode becomes a green diode or a blue diode. For an LED having blue light, indium in the range of about 22% may be used. For an LED having green light, indium in the range of about 40% may be used. The amount of indium used may be varied depending on the desired wavelength of the blue or green color. Subsequently, a p-GaN layer **180** is formed on the active layer **160**. In this instance, the p-GaN layer **180** was doped with magnesium (Mg) with a doping concentration of about 10^{17} cm^{-3} or greater.

Referring to FIG. **3**B, a transparent conductive layer **220** is formed on the p-GaN layer **180**. The transparent conductive layer **220** may be made of any suitable material including, for example, Ni/Au or indium-tin-oxide (ITO). A p-type electrode **240** is then formed on one side of the transparent conductive layer **220**. The p-type electrode **240** may be made of any suitable material including, for example, Ni/Au, Pd/Au, Pd/Ni and Pt. A pad **260** is formed on the p-type electrode **240**. The pad **260** may be made of any suitable material including, for example, Au. The pad **260** may have a thickness of about 5000 Å or higher.

Referring to FIG. **3**C, the transparent conductive layer **220**, the p-GaN layer **180**, the active layer **160** and the n-GaN layer **140** are all etched at one portion to form an n-electrode **250** and pad **270**. As shown in FIG. **3**C, the n-GaN layer **140** is etched partially so that the n-electrode **250** may be formed on the etched surface of the n-GaN layer **140**. The n-electrode **250** may be made of any suitable material including, for example, Ti/Al, Cr/Au and Ti/Au. The pad **270** is a metal and may be made from the same material as the pad **260**.

Referring to FIG. **3**D, the thickness of the substrate **100**, such as made from sapphire, is reduced to form a thinner substrate **100**A. In this regard, backside lapping is performed on the sapphire substrate **100** to reduce the wafer thickness. After backside lapping, mechanical polishing is performed to obtain an optically flat surface. After mechanical polishing, the surface roughness (Ra) may be less than about 15 nm. Such polishing technique can reduce the surface roughness up to about 5 nm or slightly less. Such low surface roughness adds to the reflective property of the surface.

In the present invention, the thickness of the substrate **100** can be controlled to be in the range of, for example, 350-430 μm. Moreover, the thickness can be reduced to less than 350 μm and to less than 120 μm. Here, mechanical polishing and dry etching techniques are used. For dry etching, inductively coupled plasma (ICP) reactive ion beam etching (RIE) may be used as an example.

Referring to FIG. **3**E, the surface roughness is further reduced to obtain a surface roughness of less than 1 nm. The surface roughness can be reduced from 5 nm up to less than 1 nm by using dry etching. One such dry etching technique is inductively coupled plasma (ICP) reactive ion beam etching (RIE) to obtain an atomically flat surface. The maximum reduction of the surface roughness further enhances the reflectivity of the surface. It is noted that depending on the type of material used for the substrate **100**, the surface roughness may be further reduced for maximum reflectivity of the surface.

Referring to FIG. **3**F, on the polished thin substrate **100**A, a reflective material **200** is formed. The reflective material **200** can be any suitable material that can reflect light. In the present example, an aluminum coating of about 300 nm thick was formed on the polished sapphire surface **100**A using an electron beam evaporation technique. Of course, other suitable deposition techniques may be used and different thicknesses of the aluminum are contemplated in the present invention. Here, the aluminum may have a concentration of about 99.999% or higher, which allows the aluminum to have a mirror-like property with maximum light reflectivity. Moreover, the reflective layer **200** entirely covers the second side of the substrate **100**A.

FIG. **5** shows an alternative embodiment in which a cladding layer **170** is formed between the p-GaN layer **180** and the active layer **160**. The cladding layer **170** is preferably formed with p-AlGaN. The cladding layer **170** enhances the performance of the diode. For simplicity, FIG. **5** does not show the p-electrode, n-electrode and the pads.

FIG. **7** shows an alternative embodiment of FIG. **5** including the p-electrode, n-electrode, and the pads.

As conceptually shown in FIGS. **2**A and **2**B, the photons generated in the active layer which head toward the polished sapphire surface and the aluminum mirror coating **200** are reflected. Such reflected photons add to the brightness of the diode (photon recovery). Adding the reflective layer and making atomically flat surface greatly increases the brightness of the diode. In addition to the reflective surface of the reflective layer **200**, it is important to note that the low surface roughness of the substrate **100** also enhances the photon reflection.

FIG. **6** is a graph showing a relationship between the light output and the injection current of, for example, a light emitting diode (LED). One curve of the graph depicts an LED having a reflective layer (in this case, an aluminum) and the other curve depicts an LED without a reflective layer. In this graph, only mechanical polishing was performed on both LED's. When the reflective aluminum layer was added to the mechanically polished surface of the sapphire substrate, the light output increased about 200% as compared to the device without the reflective layer.

FIG. **4**A shows a wafer having LEDs formed thereon. Scribe lines **300** are formed on the wafer through the buffer layer **120** from the side having the LEDs (front scribing) to separate the LED chips. The scribe lines **300** are formed using, for example, a dry etching technique or mechanical scribing. The dry etching technique such as inductively coupled plasma (ICP) reactive ion beam etching (RIE) can form very narrow scribe lines on the buffer layer **120** and the substrate **100**A. Using such dry etching technique greatly increased the number of LED chips on the wafer because the space between the chips can be made very small. For example, the space between the diode chips can be as narrow as 10 μm or lower. FIG. **4**B is an alternative method of forming the scribe lines in which the back side of the diode used.

The scribe lines may also be formed by a diamond stylus, which requires a large spacing between the diode chips due to the size of the diamond stylus itself. Also, a dicing technique may be used to separate the chips.

Once the diode chips are separated, each diode may be packaged. Such package may also be coated with a reflective material to further enhance the light output.

The present invention applies a simple and inexpensive light extraction process to the existing device fabrication process. According to this invention, adding just one more step of metallization after backside lapping and polishing allows a significant light output increase. With finer polishing using dry etching, in some cases, the light output can be as much as a factor of four without a substantial increase in production cost.

The diode of the present invention improves light intensity of a diode such as an AlInGaN-based light emitting diode (LED) using a reflective coating. The reflective coating recovers those photons, which would otherwise be absorbed by the substrate or the lead frame in the LED package. This increases the total external quantum efficiency of the quantum well devices. This invention can be applied not only to the current commercially available blue, green, red and white LEDs but also to other LED devices. Using this technique, the light output was increased by as much as a factor of four as compared to conventional LED devices (without the reflective coating) without significantly sacrificing or changing other characteristics of the diode.

Although the present invention has been described in detail with reference to GaN technology diodes, the reflector and substrate polishing technique of the present invention can easily be applied to other types of diodes including red LEDs and laser diodes including VCSELs. Although red LEDs do not use GaN, the substrate of the red LEDs may just as easily be polished and a reflective layer can easily be attached to the polished surface of the substrate, as described above. Such technique also recovers the photons to increase the light output of the diode. Similar technique is also applicable for laser diodes.

It will be apparent to those skilled in the art that various modifications and variation can be made in the present invention without departing from the split or scope of the invention. Thus, it is intended that the present invention cover the modifications and variations of this invention provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. A method of making light emitting diodes, comprising:

providing a substrate, wherein the substrate has a first side and a second side that is opposite the first side;

forming a semiconductor structure on the first side of the substrate, the semiconductor structure including a first semiconductor layer, an active layer on the first semiconductor layer and a second semiconductor layer on the active layer, wherein the active layer comprises a multiple quantum well layer, and wherein a clad layer including AlGaN is between the active layer and the second semiconductor layer;

forming a transparent conductive layer on the semiconductor structure, the transparent conductive layer including ITO (indium-tin-oxide);

forming a first electrode on the transparent conductive layer;

forming a second electrode on the first semiconductor layer facing a same direction as the first electrode;

performing backside lapping on the second side of the substrate to a substrate thickness of less than 120 μm; and

polishing the lapped second side of the substrate by inductively coupled plasma reactive ion beam etching (ICP-RIE), thereby making a roughness of the polished second side of the substrate to be less than 1 nm.

2. The method according to claim **1**, wherein an area of the transparent conductive layer is smaller than an area of the substrate.

3. The method according to claim **1**, further comprising forming an inclined surface of the substrate.

4. The method according to claim **3**, further comprising forming an inclined surface of the semiconductor structure.

5. The method according to claim **4**, wherein the inclined surface of the semiconductor structure is connected to the inclined surface of the substrate.

6. The method according to claim **3**, wherein the inclined surface of the substrate is located at a side edge of the substrate.

7. The method according to claim **1**, further comprising forming a reflective structure including Al on the polished second side of the substrate.

8. The method according to claim **1**, wherein the inclined surface of the substrate is connected to the first side or the polished second side of the substrate.

9. A method of making light emitting diodes, comprising:

providing a substrate, wherein the substrate has a first side and a second side that is opposite the first side;

forming a semiconductor structure including GaN on the first side of the substrate;

forming a transparent conductive layer on the semiconductor structure, the transparent conductive layer including ITO (indium-tin-oxide);

performing backside lapping on the second side of the substrate to a substrate thickness of less than 350 μm; and polishing the lapped second side of the substrate by inductively coupled plasma reactive ion beam etching (ICP-RIE), thereby making a roughness of the polished second side of the substrate to be less than 1 nm.

10. The method according to claim **9**, further comprising:

forming a first electrode on the transparent conductive layer; and

forming a second electrode on the first semiconductor layer facing a same direction as the first electrode.

11. The method according to claim **9**, wherein an area of the transparent conductive layer is smaller than an area of the substrate.

12. The method according to claim **9**, further comprising forming an inclined surface of the substrate and an inclined surface of the semiconductor structure.

13. The method according to claim **12**, wherein the inclined surface of the semiconductor structure is connected to the inclined surface of the substrate.

14. The method according to claim **13**, wherein the inclined surface of the semiconductor structure has a same inclination as that of the inclined surface of the substrate.

15. The method according to claim **12**, wherein the inclined surface of the substrate is located at a side edge of the substrate.

16. The method according to claim **9**, further comprising forming a reflective structure including Al on the polished second side of the substrate.

17. The method according to claim **9**, wherein the inclined surface of the substrate is connected to the first side or the polished second side of the substrate.

* * * * *